High-Temperature Electrolysis for Hydrogen Production from Nuclear Energy

HYDROGEN INITIATIVE

Research & Development

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A research and development program is under way at the INEEL on high-temperature electrolysis for hydrogen production from steam. When coupled to an advanced reactor and power cycle, this process has the potential to achieve high efficiency (45-50% vs. ~30% for conventional electrolysis), with no greenhouse gas emissions and no consumption of fossil fuels. This work is supported by the Department of Energy, Office of Nuclear Energy, under the Nuclear Hydrogen Initiative (NHI).

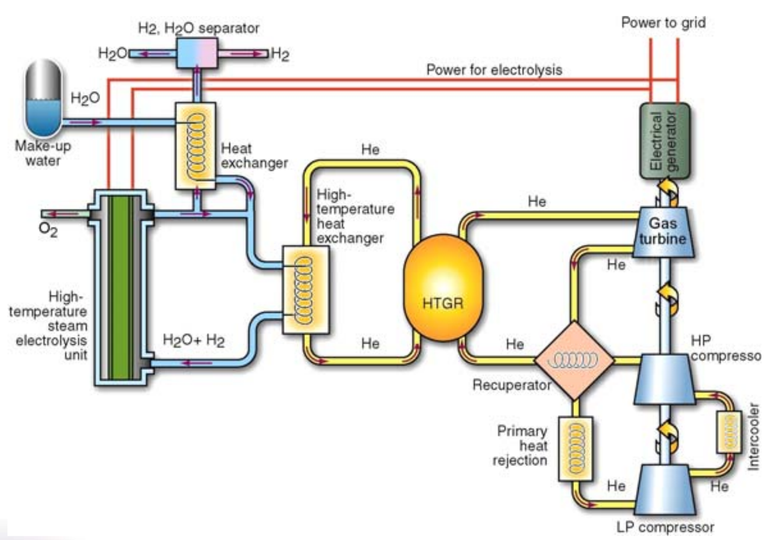
High-Temperature Electrolysis

High-temperature electrolytic water-splitting supported by nuclear process heat and electricity has the potential to produce hydrogen with an overall system efficiency near those of the thermochemical (e.g., Sulphur-Iodine) processes, but without the challenging corrosive conditions of the thermochemical processes and without the fossil fuel consumption and greenhouse gas emissions associated with hydrocarbon processes. Specifically, a high-temperature advanced nuclear reactor coupled with a high-efficiency high-temperature electrolyzer could achieve a competitive thermal-to-hydrogen conversion efficiency of 45 to 55%.

A schematic of a nuclear hydrogen plant using high temperature electrolysis is shown below. The reactor (in this case a High Temperature Gas-cooled Reactor, HTGR) supplies thermal energy to drive the power cycle and to heat steam for the electrolysis process. The high-temperature heat exchanger supplies superheated steam to the cells at a temperature of ~850ºC, and a pressure of 5 Mpa (725 psi). The input gas contains both steam and hydrogen in order to maintain reducing conditions at the electrolytic cathode. There are no moving parts within the steam electrolysis unit. While the HTE plant would be devoted primarily to the production of hydrogen, it is important to note that output of the electrical generator could be sent to the grid, if demanded. Conversely, the steam flow rate could be increased and the electrolyzer could be operated at a higher current density to profitably accept power from the grid for increased hydrogen production in times of low electrical demand. Thus HTE can play an important role in matching the constant output of future reactors to varying electrical demands.

Research on Solid-Oxide Electrolysis Cells

A research and development program is under way at INEEL to develop materials and techniques for high-temperature electrolytic production of hydrogen using solid-oxide cells. Solid-oxide cells have been developed primarily for power production in the fuel-cell mode of operation. In the fuel-cell mode, hydrogen and oxygen are combined electro-chemically to produce water, liberating heat and electricity. Operated in reverse, solid-oxide cells can achieve water splitting to produce separate streams of hydrogen and oxygen, while consuming electrical power and heat. The efficiency of this simple process increases with increasing temperature for reasons related to both thermodynamics and



High Temperature Electrolysis system coupled with Gas-cooled Reactor.

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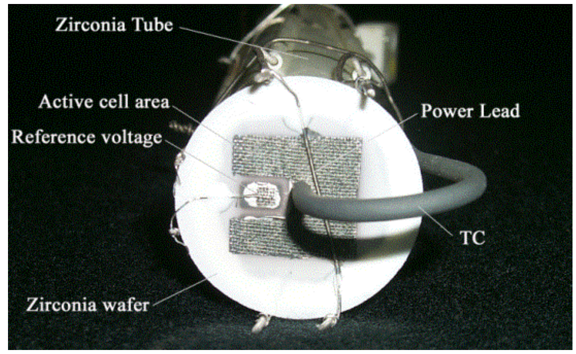
materials behavior. Thermodynamically, operation at high temperature reduces the electrical energy requirement for electrolysis and also increases the thermal efficiency of the power-generating cycle. In terms of materials, ohmic losses are reduced at high temperature. Ohmic losses can also be reduced by minimizing the thickness of the electrolyte and/or by using higher ionic conductivity electrolytes. In planar stack configurations, special attention must also be given to the design of the bipolar interconnect plates to minimize contact resistance. We are working with Ceramatec, Inc. of Salt Lake City to address these materials and design issues.

We have developed a solid-oxide electrolysis test capability at INEEL. To date, we have acquired detailed performance characterization data on individual button cells manufactured by Ceramatec, Inc. A close-up photo of one of these "button cells" is shown above. The button cell is cemented to a zirconia tube and the apparatus is suspended in the furnace. A steam-hydrogen mixture is introduced into the interior of the zirconia tube with a sweeping flow of air on the exterior of the tube inside the furnace. The active electrode area is 2.5 cm^2, with a small additional inactive area serving as a reference electrode. The button cell temperature is measured by the thermocouple (TC) shown. The cathode (in electrolysis mode) is a nickel zirconia cermet and the anode (visible in the photograph) is strontium-doped lanthanum manganite. A platinum wire mesh is used on the button cell electrodes for optimal current distribution. The wire mesh would not be included in a stack configuration since the interconnect plate serves as a current distributor in that case. These are electrolyte-supported cells with an electrolyte thickness of approximately 125 µm, fabricated from either yttria-stabilized zirconia or



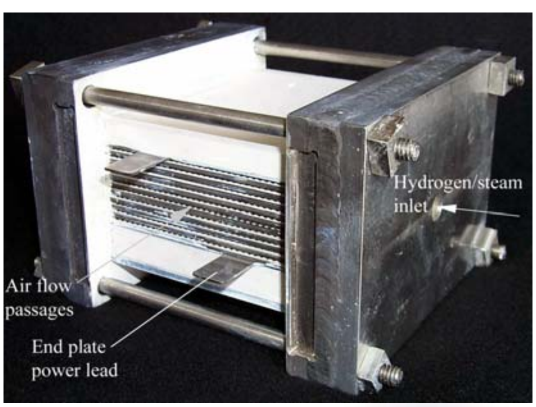
Instrumented electrolysis button cell.

scandia-stabilized zirconia. Electrode-supported cells with very thin electrolytes (~10 µm) are also under development. In this case, advanced chemical vapor deposition (CVD) techniques are used to deposit the electrolyte material.

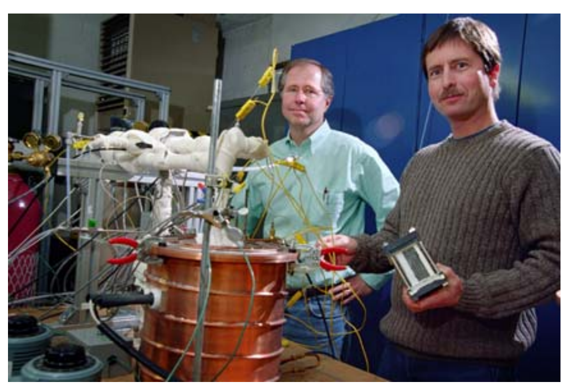
Electrolysis stack testing has already been performed at Ceramatec as part of this program. A six-cell electrolysis stack was operated for over 1100 hours, producing 35 normal liters of hydrogen per hour (Nl/hr), a rate equal to the largest operational S-I thermochemical experiment to date.

Systems Analysis and Scale-Up

Conceptual design and systems analysis for large- and intermediate-scale facilities for the production of hydrogen via planar solid-oxide electrolysis technology is also under way. The Research and Development Plan for the NHI calls for the deployment of a Pilot-Scale (500 kW) demonstration facility for HTE in the 2008 time frame. A pre-conceptual design for this facility has been completed. It would be capable of achieving a hydrogen production rate of 2780 Nl/min. The NHI R&D plan also calls for a larger 5 MW engineering demonstration facility to be developed in the 2013 time frame.



Assembled 10-cell electrolysis stack.



High temperature electrolysis research at the INEEL.